



# Atmospheric Pressure Plasma Jet as a Dry Alternative to Inkjet Printing in Flexible Electronics

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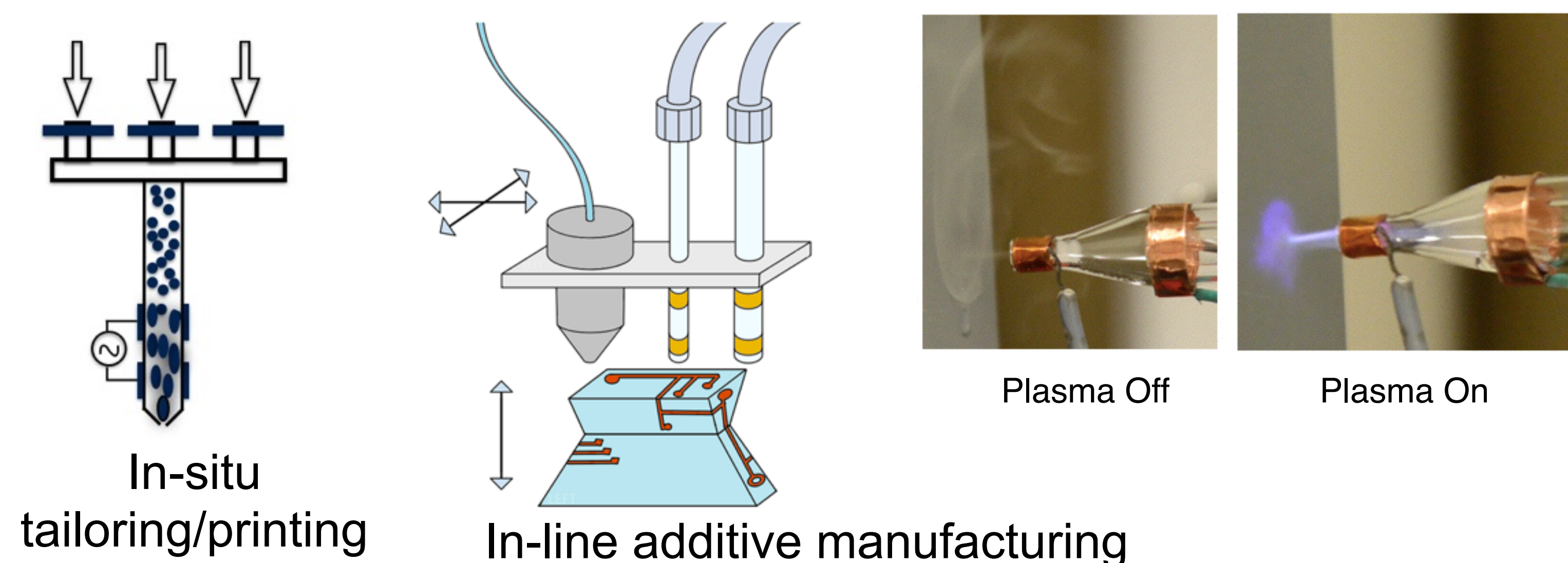
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## Abstract

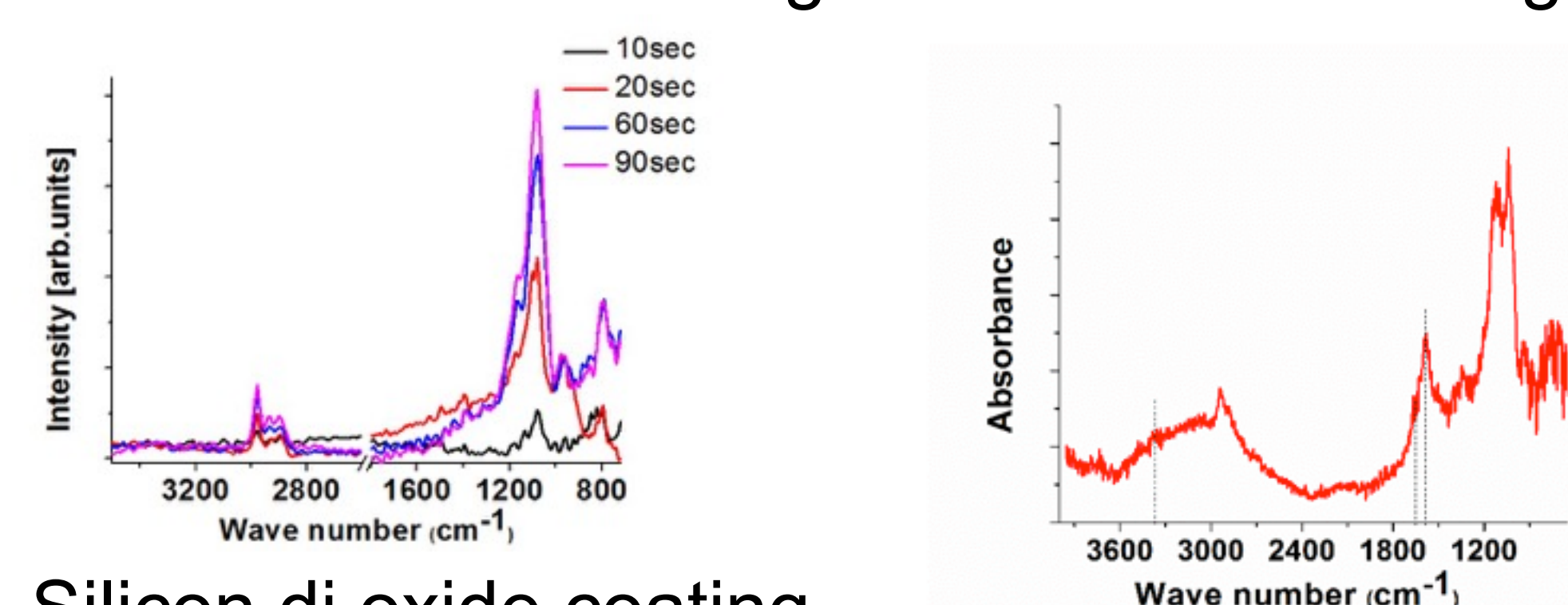
We have developed an atmospheric pressure plasma jet printing system that works at room temperature to 50 deg C unlike conventional aerosol assisted techniques which require a high temperature sintering step to obtain desired thin films. Multiple jets can be configured to increase throughput or to deposit multiple materials, and the jet(s) can be moved across large areas using a x-y stage. The plasma jet has been used to deposit carbon nanotubes, graphene, silver nanowires, copper nanoparticles and other materials on substrates such as paper, cotton, plastic and thin metal foils.

## Plasma Jet Multi-Material Printer

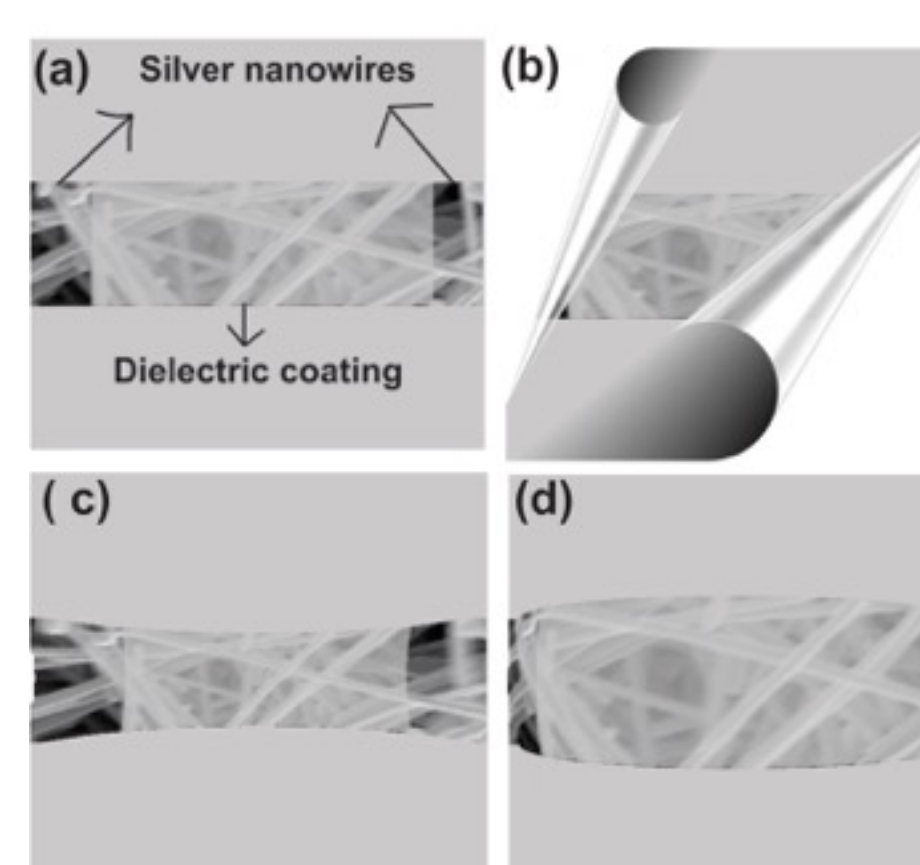


- Nanocolloids, organic materials etc. transported as aerosol by carrier gas
- Precise control over thickness and morphology
- Ability to tailor material properties in situ (chemical, electronic)
- Can be combined as an in-line manufacturing process in additive manufacturing

### Low & High K Dielectric Coating



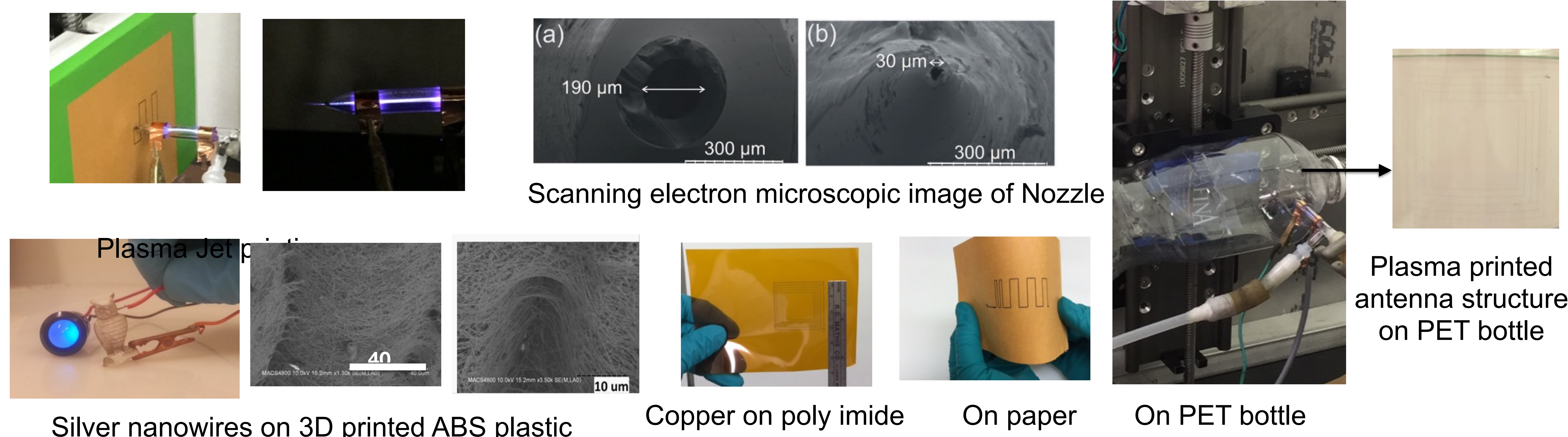
### Silicon dioxide coating



### Nitrogen-incorporated silicon oxide coating

Thin gate dielectric, passivation layer in microelectronics  
Optical waveguides (varying refractive index)

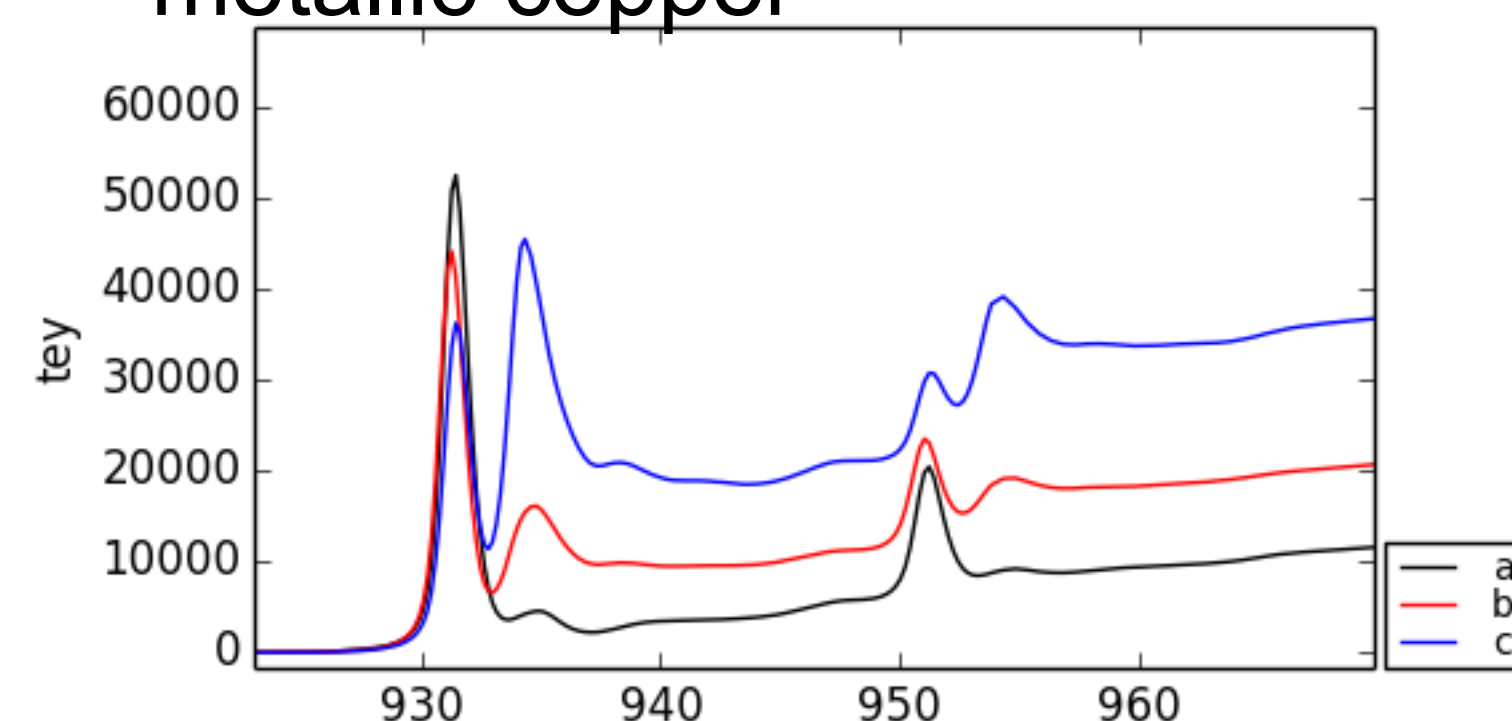
## Plasma Jet Printed Electronics



Plasma printed antenna structure on PET bottle

## In-situ Tailoring of Material Properties

In-situ reduction of Cu<sup>2+</sup> to metallic copper



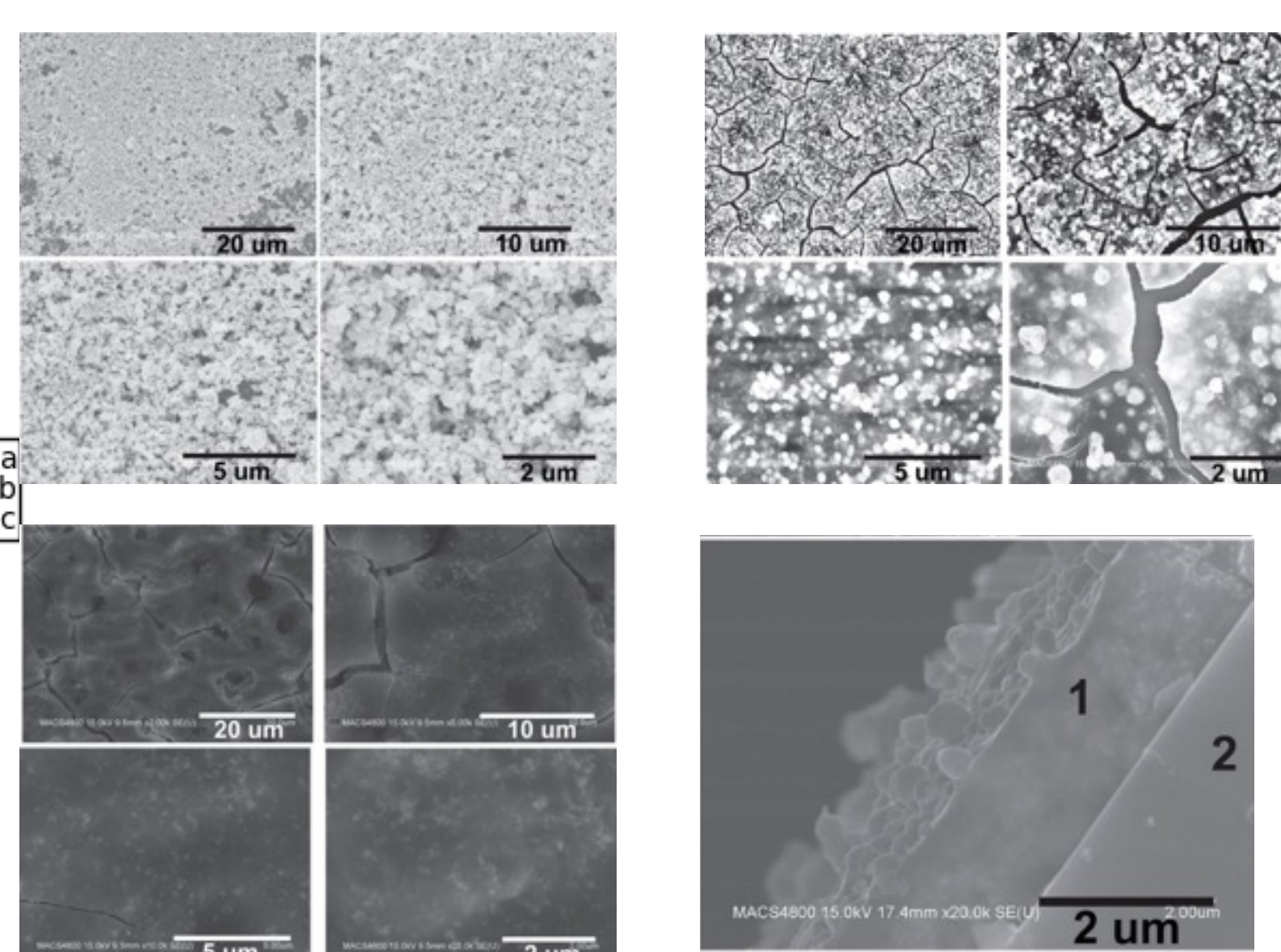
Cu L edge XAS mono

No post processing, No pre-post thermal treatment

Printed using same colloid

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Controlled surface characteristics



Cross sectional SEM of Cu(1) on Silicon(2)

## Contacts & Reference

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- (1) Three US Patent applications pending
- (2) Ram P. Gandhiraman et al., *Applied Physics Letters*. **2016**, 108, 123103.
- (3) Ram P. Gandhiraman et al., *ACS Appl Mater Interfaces*. **2014**, 6, 20860
- (4) Ram P. Gandhiraman, Dennis Nordlund, Vivek Jayan, M. Meyyappan, Jessica E. Koehne. *ACS Appl Mater Interfaces*. 2014, 6, 22751.
- (5) <https://www.sciencedaily.com/releases/2016/03/160322120038.htm>